Columbia University
in the City of New York

LAMONT GEOLOGICAL OBSERVATORY
PALISADES, NEW YORK

TRANSISTORIZED SEISMIC EQUIPMENT FOR REFRACTION MEASUREMENTS AT SEA

by
Bernard Luskin and D. E. Koelsch

Technical Report No. 17
CU-46-58 NObsr 64547 Geol.

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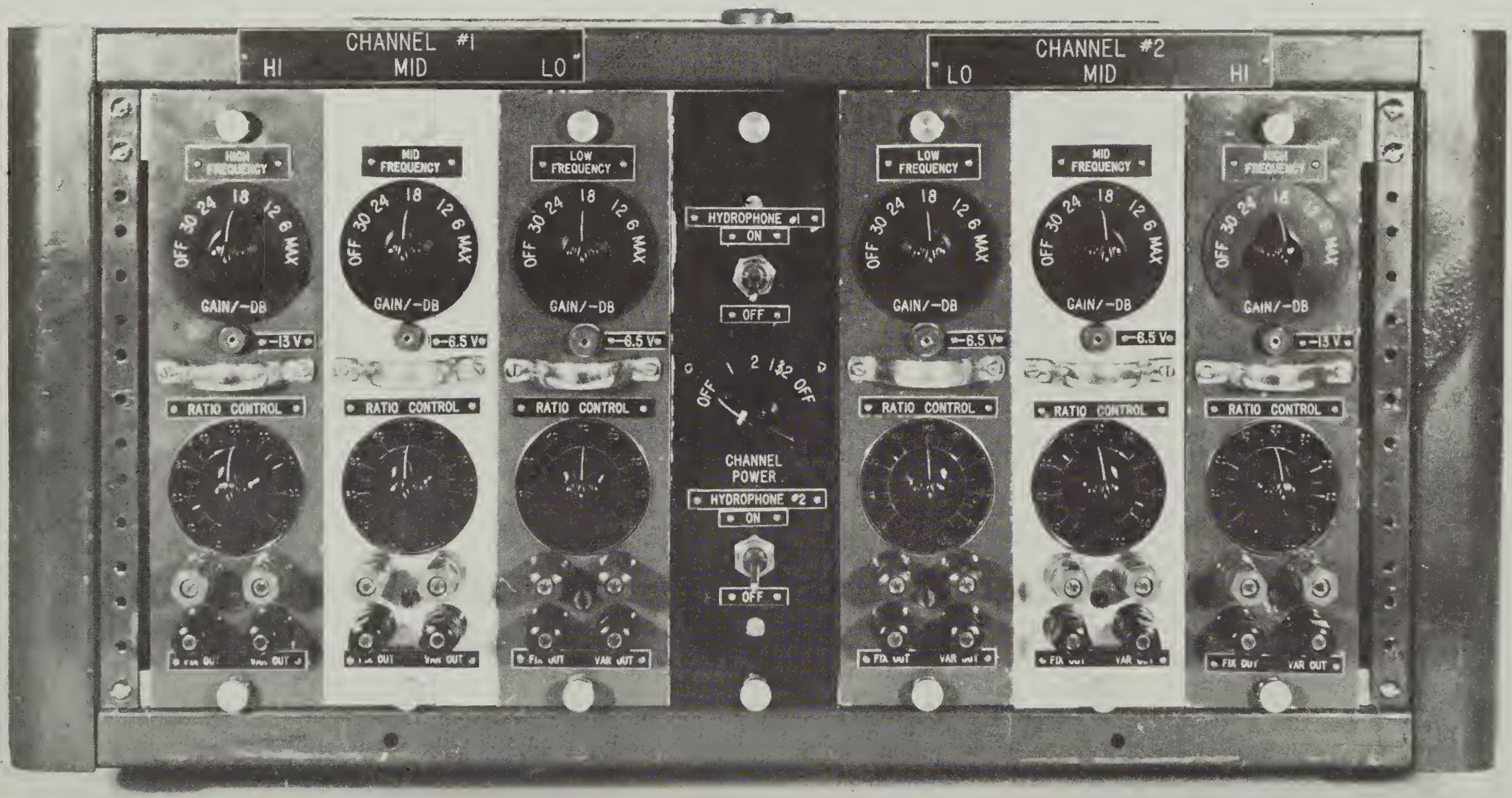

FIGURE 1 TRANSISTORIZED SEISMIC EQUIPMENT

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I GENERAL DESCRIPTION

A. Introduction

This report covers the essential information required for installation, operation and maintenance of a Transistorized Seismic Equipment used for making refraction measurements at sea. This equipment is intended to replace the gear aboard the Research Vessel VEMA and other vessels used by the Lamont Geological Observatory for seismic work at sea.

The design of the equipment is based upon the use of two new electronic components - the transistor and the mercury battery. Since seismic refraction measurements are made under conditions of "quiet ship," the entire recording apparatus must, of necessity, be operated from battery power. Seismic recording gear utilizing vacuum tubes presents a difficult supply problem when provisioning a ship for a long cruise. Usually, the required batteries cannot be bought at ports of call so that sufficient spares must be stored at the beginning of the cruise. It is therefore necessary to seal and package large quantities of batteries in order to preserve their shelf life for a reasonably long period. A typical seismic recording installation using vacuum tube amplifiers requires 8 'B' batteries and two storage batteries weighing some 200 pounds and occupying some 3 cubic feet of space. The transistorized equipment requires 8 mercury batteries, each weighing 3/4 of an ounce and occupying a volume of about 4.3 cubic inches. Furthermore,

both the operating and shelf lives of the transistor power supply are longer than those of the vacuum tube battery supply.

The design of the Transistorized Seismic Equipment is also based upon considerations of maximum ease of operation and maintenance. All the necessary controls and the galvanometer connections are at the front of the equipment. The power to all amplifiers is controlled by a single switch. The components used are operated well under rating. The Low Frequency and Mid Frequency Amplifiers have been designed so that they can be interchanged with only minor modifications. The internal construction of the amplifiers has been deliberately spaced out so that signal tracing and component replacement may be done easily under usual sea-going conditions.

B. Basic Principles

Seismic refraction measurements are made at sea with the use of two ships, one ship running a course and shooting explosive charges, the other ship remaining hove to and recording the seismic energy propagated along various paths from the explosion. A study of the records so obtained reveals information about the thickness and the velocity of sound in the various layers beneath the ocean bottom.

The arrivals recorded of the seismic energy traveling the various paths are classified as Ground Waves (G), Direct Water Wave (D), and Reflected Water Waves (R1, R2, etc.).

Ground Waves are those which have traveled through sedimentary or rock layers underlying the ocean bottom and consequently much of the higher frequency energy content of these waves is highly attenuated. G

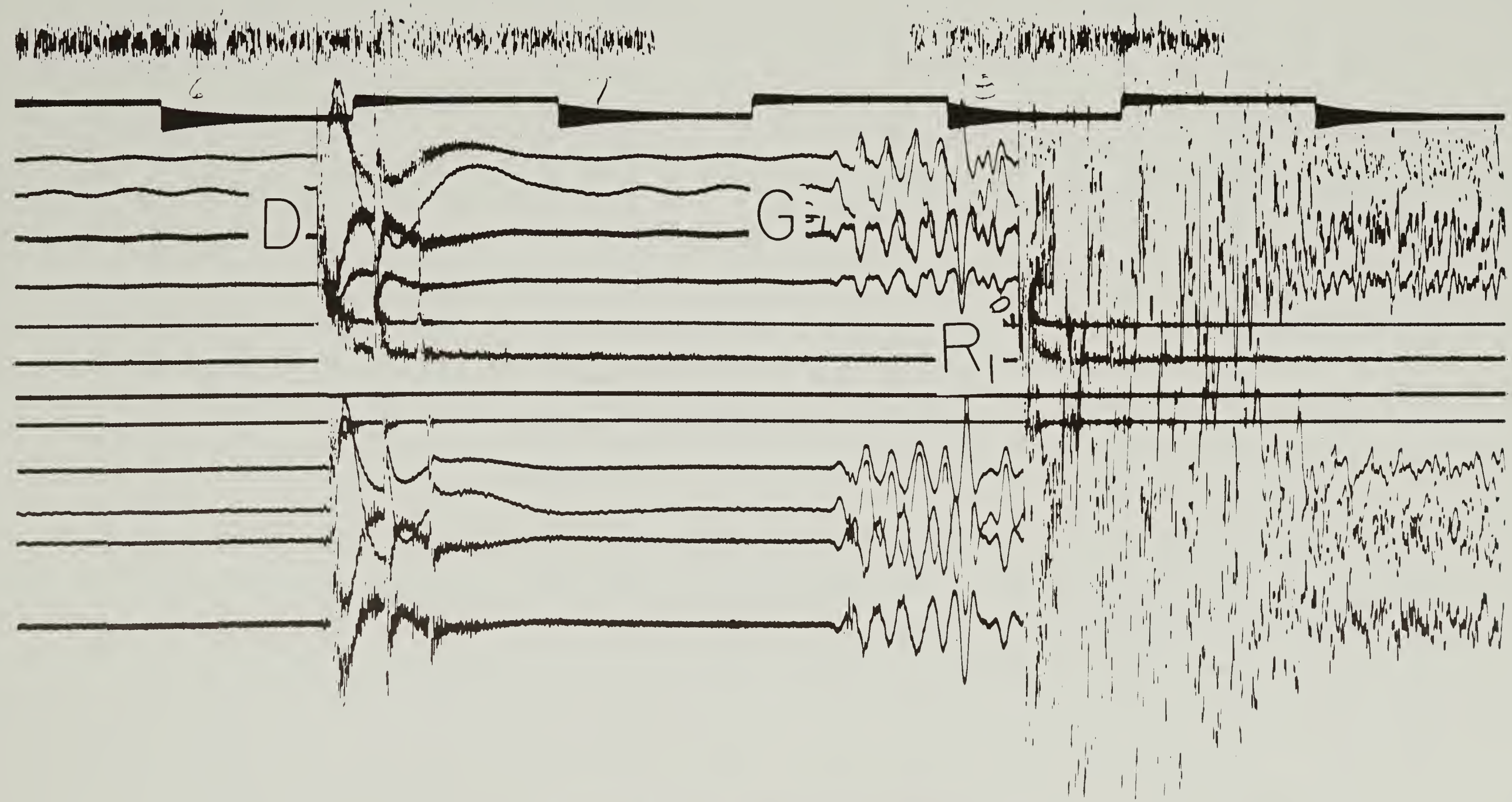


FIGURE 2 TYPICAL SHOT RECORD

arrivals are therefore of predominantly low frequency content (below 200 cycles per second), low amplitude and emergent character.

D is the direct Water Wave between the two ships. It is usually a strong signal of predominantly high frequency content (1000 cps up) and of impulsive character.

The Reflected Water Waves are those which have traveled through the water and have been reflected from the bottom and/or surface of the water one or more times. These waves vary widely in amplitude and have a broad frequency spectrum. The low order reflections produce arrivals which resemble D in character. The higher order reflections produce arrivals which tend to be emergent in character and of lower frequency content.

Recordings are made aboard a 'quiet ship'. This means that the recording ship is hove to and has all machinery shut down except the motor required to drive the film through an oscillographic recorder. The usual recorder or geophysical camera contains about 14 optical galvanometers. One or two of these are generally used for the recording of radio signals, timing pulses or other information required to correlate the shot time with the arrival times. The other galvanometers are used to record the seismic signals at various levels of amplification and with various frequency passbands.

The Transistorized Seismic Equipment (TSE) provides the amplification, filtering and impedance matching required to pass the signals received by the hydrophones to the recording galvanometers. Two hydrophones are always used to reduce the probability of mistaking a jerk of the hydrophone cable for a Ground Wave. Just before shot time the cables are slacked off

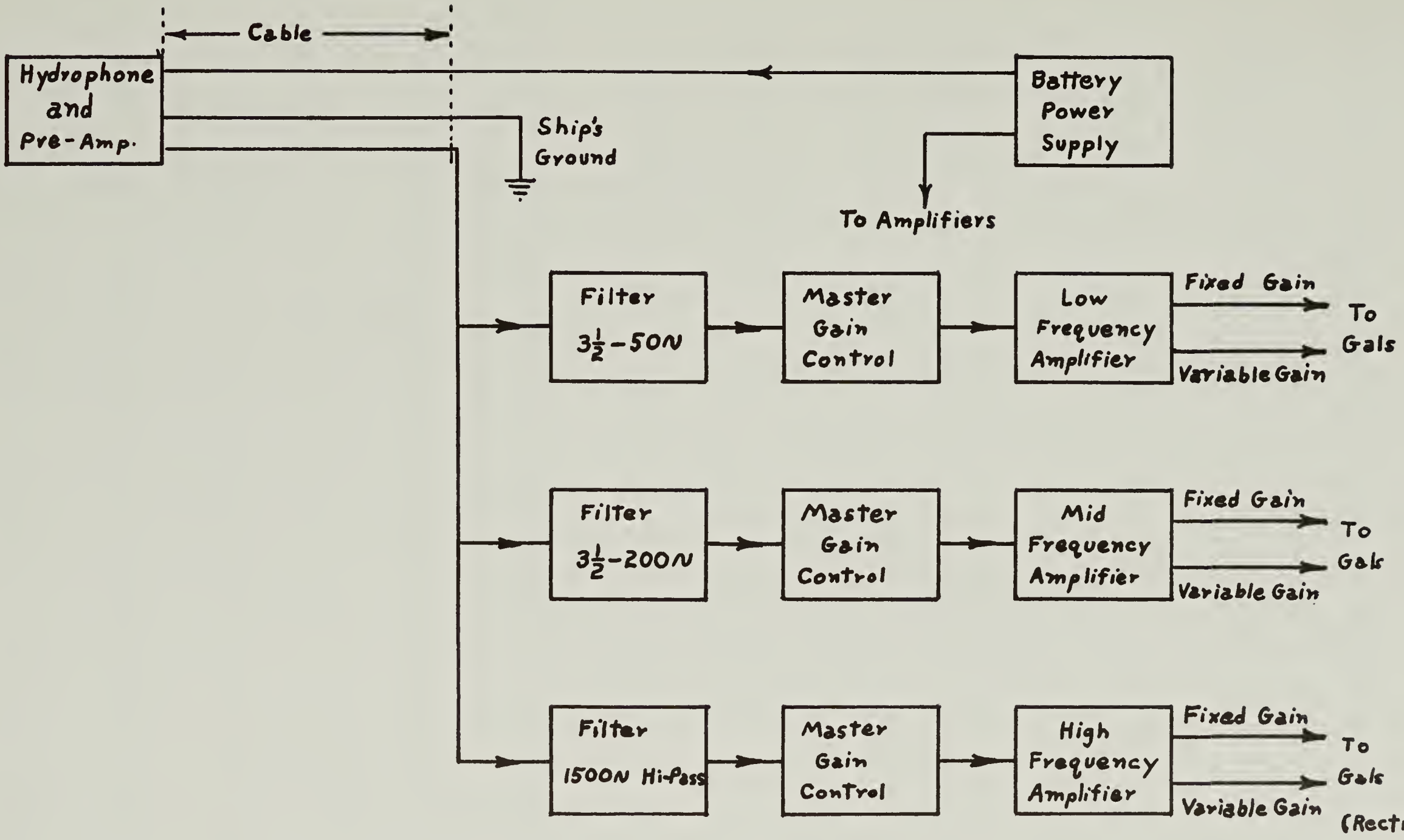


FIGURE 3 TSE BLOCK DIAGRAM

rapidly so that the hydrophones are slowly sinking through the water during the recording period and have a minimum amount of coupling with the motions of the ship. The TSE provides outputs for six galvanometers for each hydrophone signal.

The six outputs are arranged in three frequency bands, two galvanometers to a band. The Low Frequency band covers the range 3 1/2 to 50 cps, the Mid Frequency Band covers the range 3 1/2 to 200 cps and the High Frequency band covers the range 1500 cps and up. The two outputs in each frequency band are further subdivided into a High Gain and Low Gain output with provision for varying the High/Low Gain ratio.

The TSE thus provides means for recording signals over a wide dynamic range and for separating the signals of different frequency content so that the character of the various arrivals may be clearly recorded.

C. General Description

The TSE is a compact equipment housed in a cabinet containing six plug-in amplifiers, a plug-in battery pack supplying power to the amplifier units, and the connectors, controls, and battery supply for the hydrophone preamplifier.

Each amplifier supplies two galvanometer outputs, one output level being fixed by the master gain control, the other output level being further attenuated by a ratio gain control. The ratio of amplification levels of the two outputs is variable from 1 to infinity. The Red, Yellow and Blue Amplifier Units supply Low, Mid and High Frequency outputs respectively. The Black plug-in unit contains the battery supply for all six amplifiers.

The high voltage battery power supply for the hydrophone preamplifiers is housed at the rear of the cabinet. For operation of the Lamont Geological Observatory preamplifier, these batteries are all that are required since the filament batteries of the preamplifier are contained in the hydrophone case. However, provision is also made for operation of the TSE with the Woods Hole Oceanographic Institution preamplifier which requires a storage battery filament supply aboard ship. Connection terminals are provided at the rear of the cabinet for the storage battery leads, and a rheostat control for adjusting the filament current for each WHOI preamplifier.

The various components of the TSE equipment are illustrated in Figures 13 through 18.

II CIRCUIT DESCRIPTION

A. General

A complete refraction channel consists of a hydrophone, a preamplifier contained in the hydrophone housing, a cable connecting the preamplifier output to the TSE, three amplifiers and six galvanometers. The TSE provides the amplifiers and battery supply required for two such recording channels.

Power is supplied to the hydrophone preamplifier by means of the receptacle at the rear of the TSE cabinet. The preamplifier signal enters the cabinet here and is passed to the paralleled inputs of the three amplifiers. Signal and battery supply enter each amplifier through the plug mounted at the rear of each amplifier plug-in unit. The galvanometer connections to each amplifier are made through the binding-post terminals on the front panel of

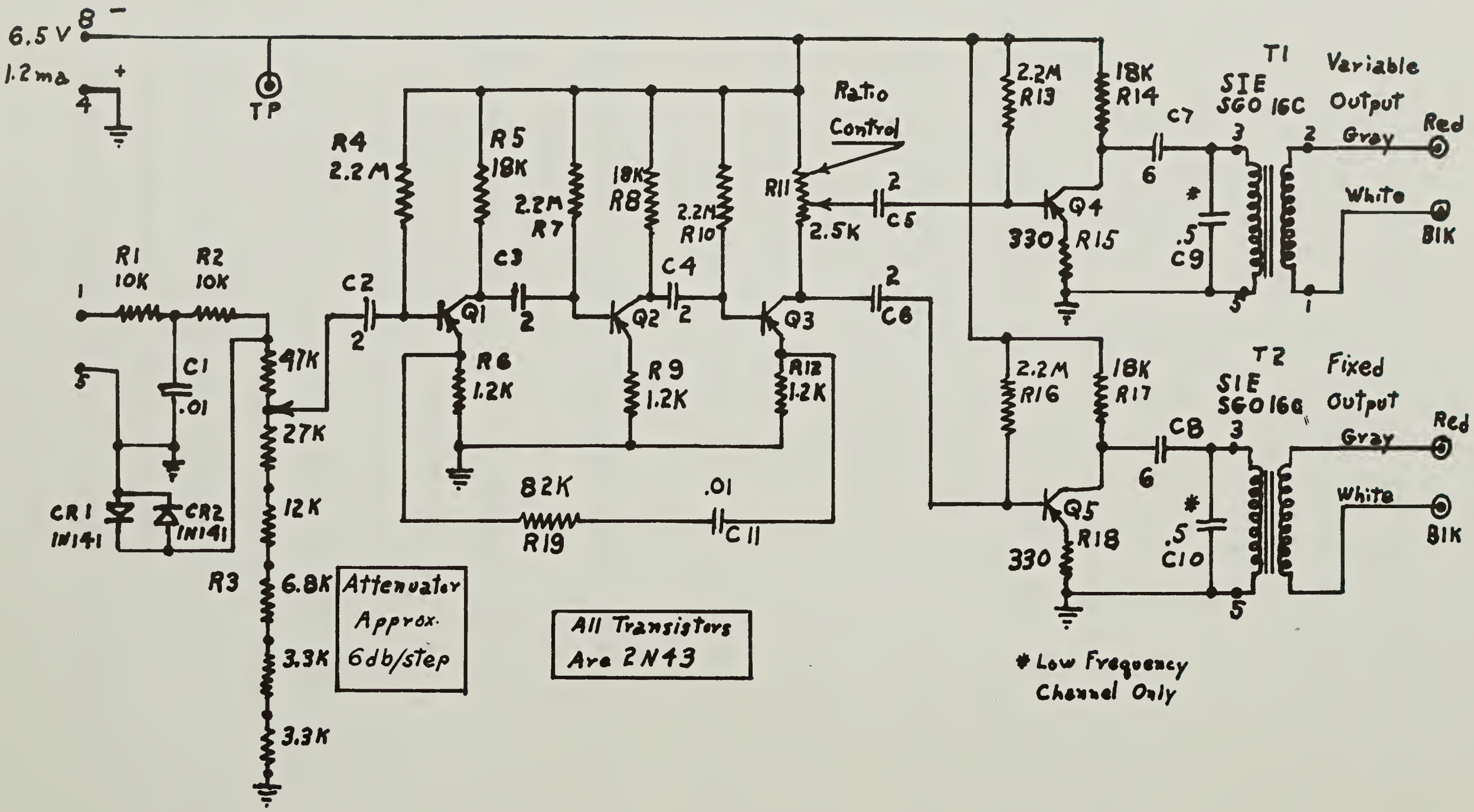


FIGURE 4 TSE LOW AND MID FREQUENCY AMPLIFIER CIRCUIT

of each amplifier plug-in unit.

The signal in each amplifier passes successively through a filter, a step-attenuator, and a three-stage voltage amplifier. At the output of the voltage amplifier, the signal is split and passed to two independent output stages which are transformer-coupled to the galvanometers. One output stage has fixed gain, i.e., the gain determined by the step-attenuator at the input. The other output stage has an additional gain control provided by a potentiometer in the last stage of the voltage amplifier.

The circuit signal return and the amplifier chassis are all grounded to sea water at one point - the grounding post at the rear of the cabinet. Note that since PNP-type transistors are used in the amplifiers, the ground side of the amplifier battery supply is the positive one. The ground side of the hydrophone preamplifier battery supply is the negative one. The galvanometer outputs are completely isolated from the rest of the circuit and from ground. However, the galvanometer outputs of each amplifier are connected with the same polarity, i.e., the top terminals of each output will have the same phase relation to the bottom terminals for a given signal.

B. Low Frequency Amplifier

Refer to Figure 4. Signal enters the amplifier through Pin 1 on the rear plug and passes first through the low pass filter consisting of R1, R2 and C1. Diodes CR1 and CR2 suppress high voltage transients and prevent blocking. The signal level is controlled by step-attenuator R3 which is arranged to provide approximately 6 db. per step. The signal then enters the voltage amplifier consisting of three RC- coupled stages with a feedback

network (R19, C11), from last to first emitter. The input impedance at the amplifier input is approximately 100,000 ohms.

The collector resistor of the third stage, R11, is a 2500 ohm potentiometer and is used to provide attenuation control for the variable gain output stage, Q4. The input to the fixed-gain output stage, Q5, is obtained directly from the collector of Q3.

The output stages are capacitive-coupled to output transformers T1 and T2. These are geophysical output transformers (SIE SGO 16C) and have essentially flat frequency response down to 5 cycles per second. The large coupling capacitors, C7 and C8, are required to prevent DC current from passing through the 20,000 ohm primary of the transformers and ruining their low frequency response. The output impedance of the transformers is 12.5 ohms.

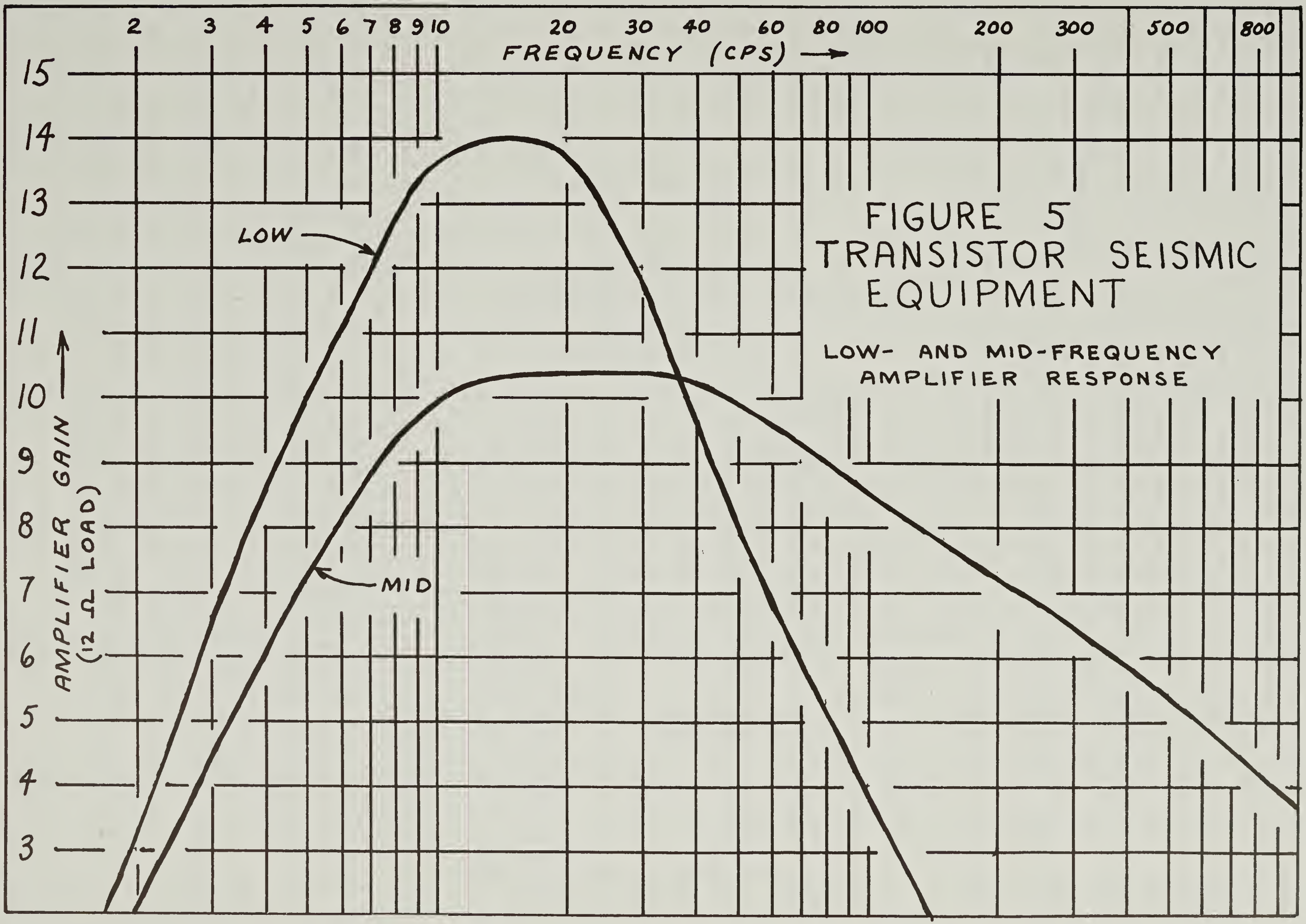
Tuning capacitors C9 and C10 are connected across the primaries of T1 and T2 to provide additional low-pass filtering.

The amplifier operates from a 6.5 volt battery supply and draws about 1.2 milliamperes. The positive side of the battery supply is connected to circuit ground.

A frequency response curve of the low frequency amplifier channel is shown in Figure 5.

C. Mid-Frequency Amplifier

This amplifier is identical to the Low Frequency Amplifier except that capacitors C9 and C10 (Figure 4) are omitted. A frequency response curve of the mid-frequency amplifier channel is shown in Figure 5.


2 3 4 5 6 7 8 9 10 20 30 40 60 80 100 200 300 500 800
FREQUENCY (CPS) →
15 14 13 12 11 10 9 8 7 6 5 4 3
AMPLIFIER GAIN (12 Ω LOAD)
LOW
MID
FIGURE 5
TRANSISTOR SEISMIC EQUIPMENT
LOW- AND MID-FREQUENCY AMPLIFIER RESPONSE

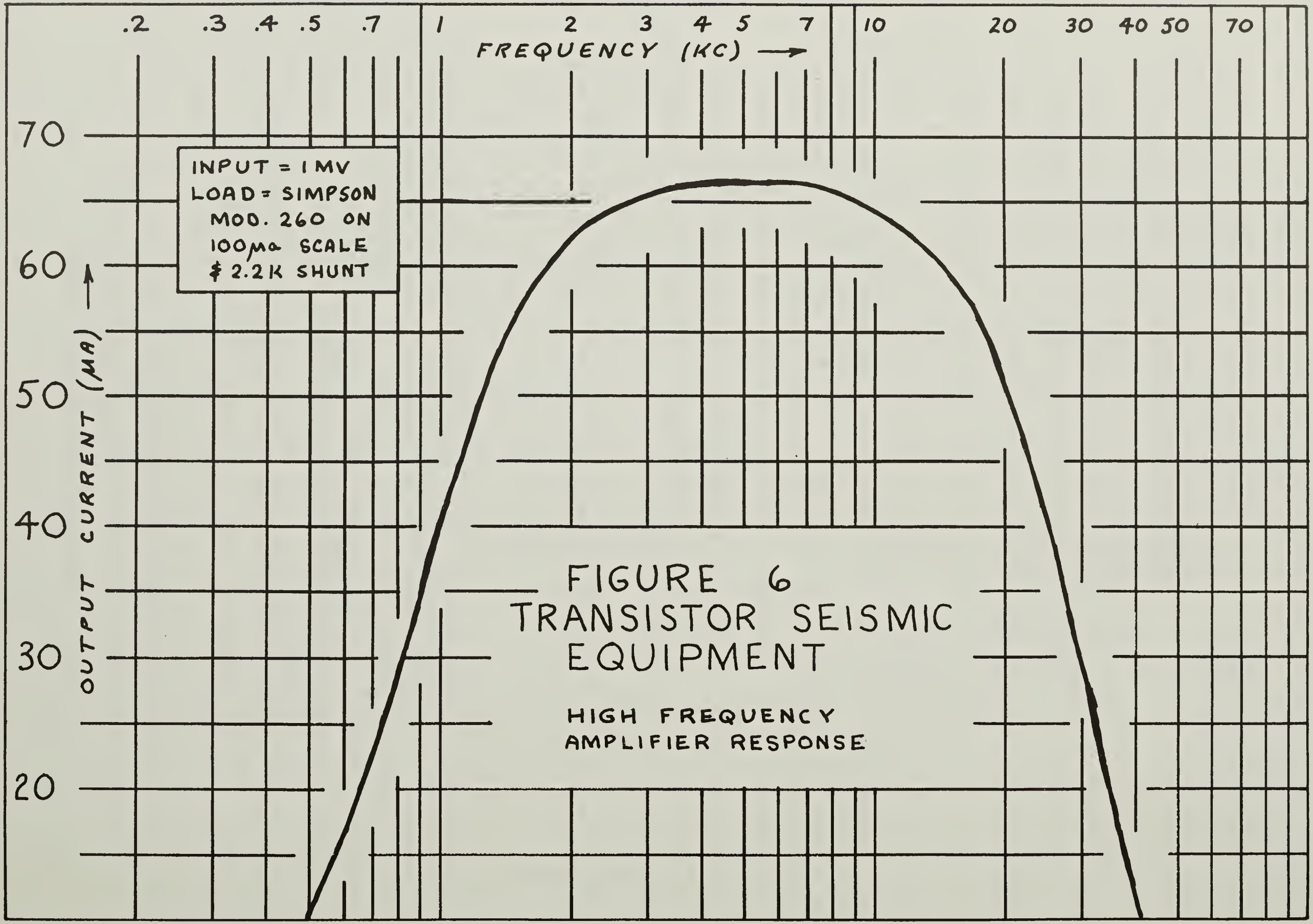


FIGURE 6
TRANSISTOR SEISMIC
EQUIPMENT

HIGH FREQUENCY
AMPLIFIER RESPONSE

D. High Frequency Amplifier

Refer to Figure 7. Signal enters the amplifier through Pin 1 on the rear plug and passes first through the high pass filter consisting of C101, C102 and R101. The signal level is controlled by step-attenuator R102 which is arranged to provide approximately 6 db. per step. The signal then enters the voltage amplifier consisting of three RC-coupled stages, Q101, Q102 and Q103. The input impedance at the amplifier input is approximately 30,000 ohms.

The collector resistor of the third stage, R110, is a 2500 ohm potentiometer and is used to provide attenuation control for the variable gain output stage, Q104. The input to the fixed-gain output stage, Q105, is obtained directly from the collector of Q103.

Capacitor C106 is used to bypass R111, the emitter resistor of Q103, and provide additional high pass filtering.

The output stages are transformer-coupled amplifiers and provide a rectified signal to the galvanometers. The dc output signal is required because the galvanometers normally used have high frequency cutoffs considerably below the 1500 cycle lower limit of the high pass channel. The half-wave rectifier circuit consists of germanium diode type 1N141 and the secondary resistance of the output transformer. T101 and T102 are plate-to-grid transformers and have a secondary resistance of about 13,500 ohms. This high resistance makes the output essentially a constant current source and provides good amplitude linearity at the very low currents required to drive the geophysical galvanometers.

The amplifier operates from a 13-volt battery supply and draws about 2 milliamperes. The positive side of the battery supply is connected to circuit ground.

A frequency response curve of the high frequency amplifier channel is shown in Figure 6.

E. Lamont Geological Observatory Hydrophone Circuit

Refer to Figures 8 and 9. Signal is generated by the Brush AX-58 Hydrophone, a Rochelle Salt transducer, and is passed to the grid of V201. The circuit consists of a 1U4 tube connected as a cathode-follower with an input impedance in excess of 40 megohms. The signal comes off the cathode of V201 at a gain of about .9 and passes up the cable and into the TSE amplifiers through pin A.

B-plus power is supplied to the circuit at 90 volts through pin G. The high voltage also energizes relay K201 which closes the 1U4 filament connection to the mercury cells, B201. The rated operating life of the filament battery supply in this circuit is over 500 hours, which amounts to the same as shelf life under usual operating conditions.

Calibration signals may be placed in series with the hydrophone by passing oscillator current through pin C and R205.

F. Woods Hole Oceanographic Institution Hydrophone Circuit

Refer to Figure 10. Signal is generated by the Brush AX-58 Hydrophone, a Rochelle Salt transducer, and is passed to the grid of V301. The circuit consists of a 7F8 tube connected as a cathode-follower with an

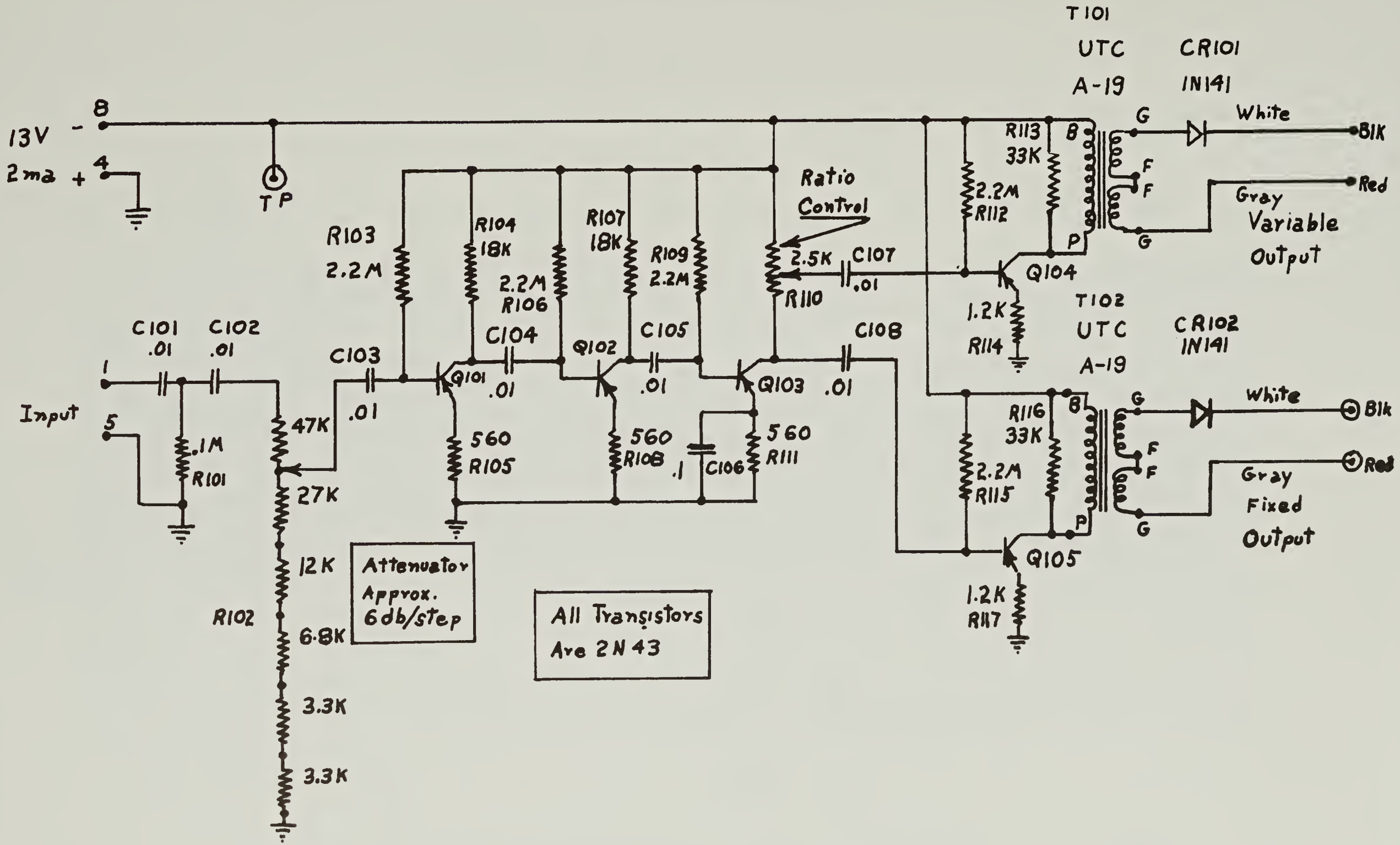


FIGURE 7 TSE HIGH FREQUENCY AMPLIFIER CIRCUIT

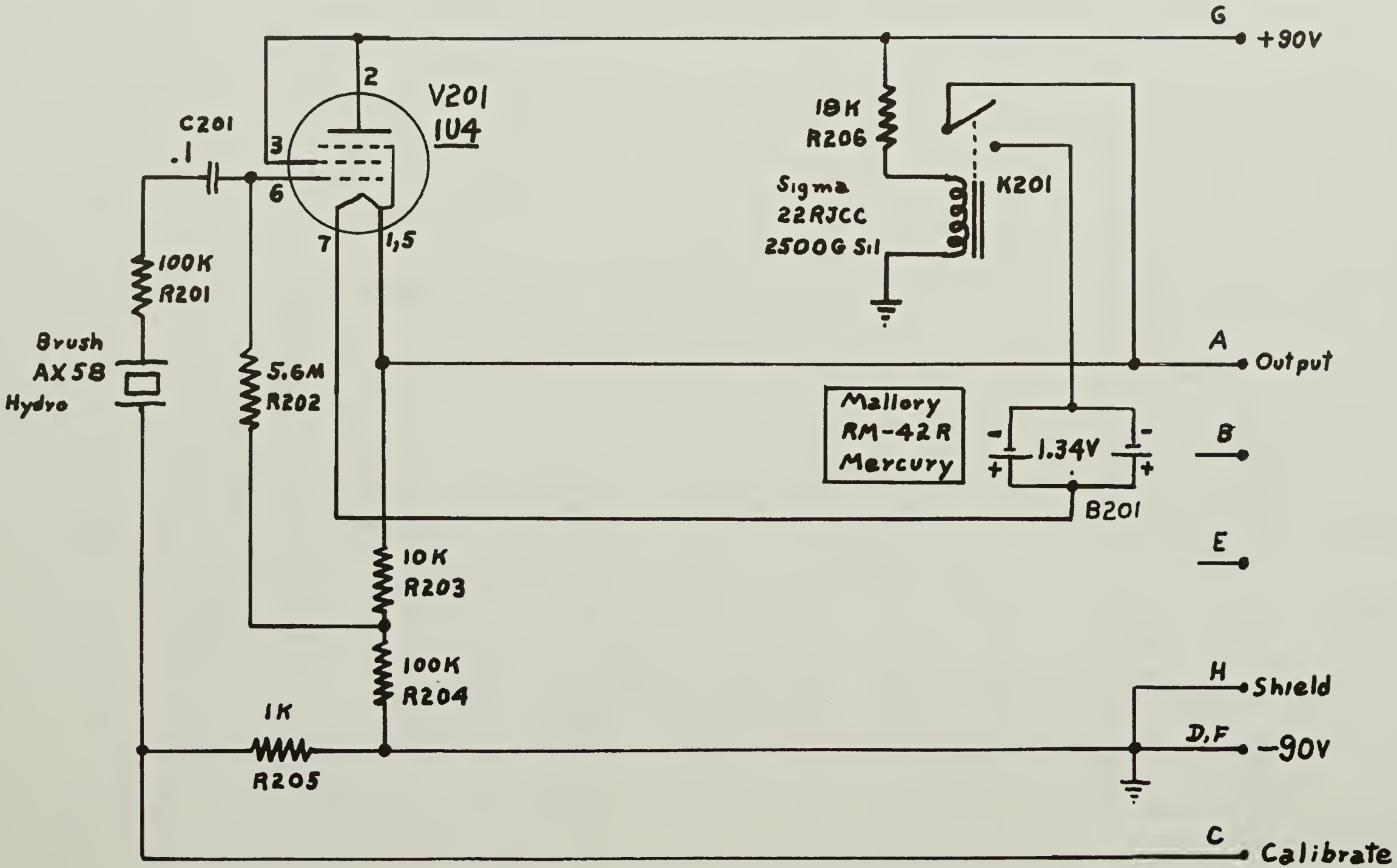


FIGURE 8 LGO HYDROPHONE CIRCUIT

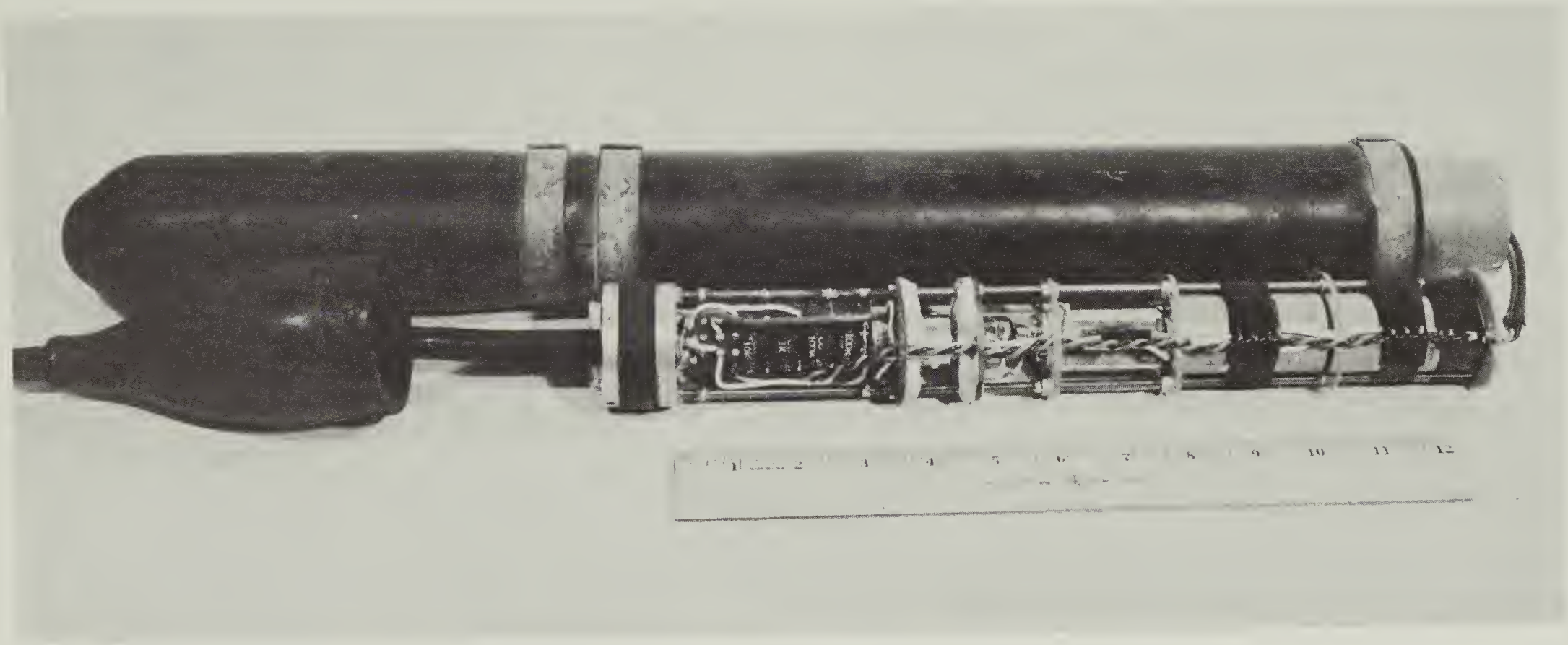


FIGURE 9 LGO HYDROPHONE AND PREAMPLIFIER

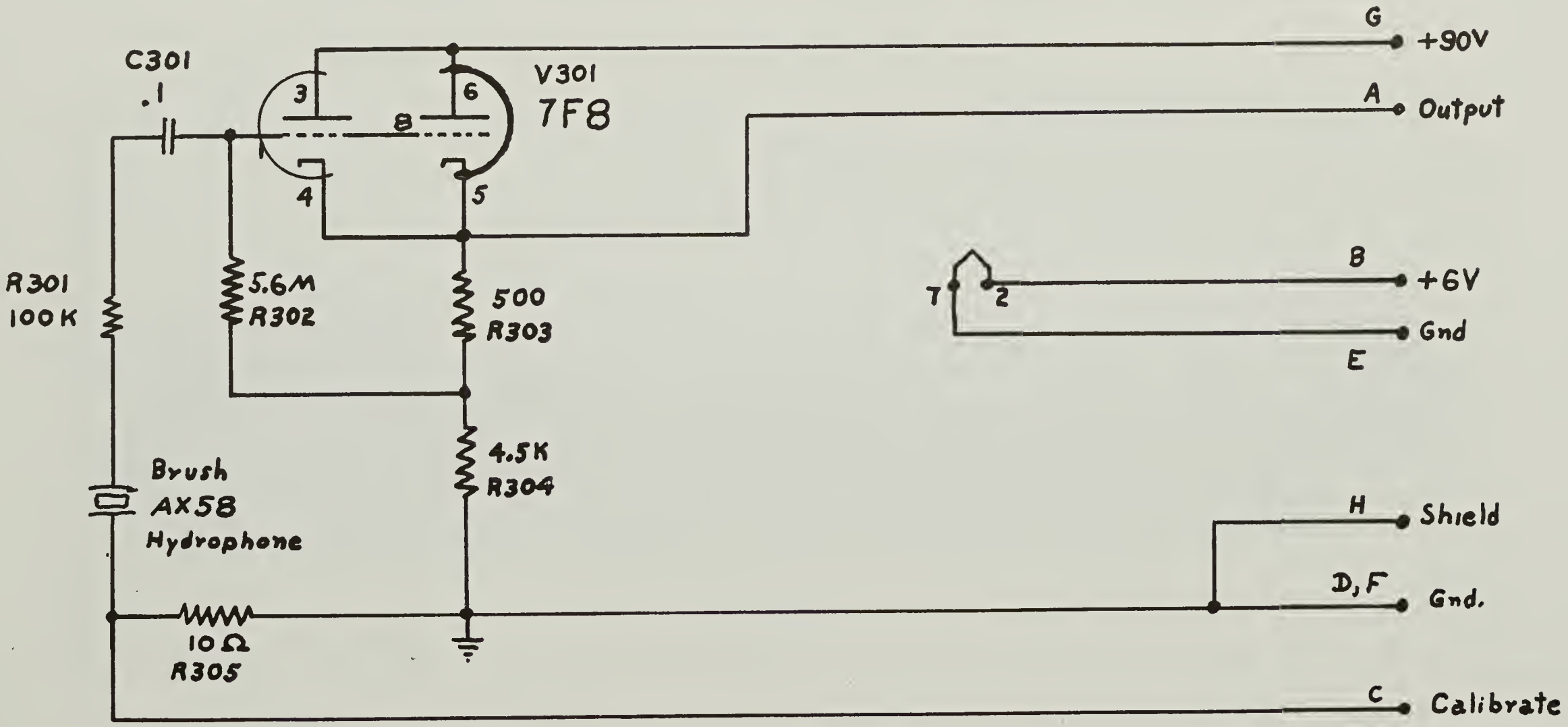


FIGURE 10 WHOI HYDROPHONE CIRCUIT

input impedance in excess of 50 megohms. The signal comes off the cathode of V301 at a gain of about .9 and passes up the cable and into the TSE amplifiers through Pin A.

B-plus power is supplied to the circuit at 90 volts through Pin G. Filament power is supplied through Pin B at 6 volts. The 300 milliampere filament current required is usually supplied by storage batteries connected to the terminal board at the rear of the TSE cabinet.

Calibration signals may be placed in series with the hydrophone by passing oscillator current through Pin C and R305.

G. Amplifier Power Supply

Refer to Figures 11 and 18. The battery supplies, B401-B406, supply power to the six transistor amplifiers. The 6.5 volt supplies are for the Low- and Mid-Frequency amplifiers and the 13 volt supplies are for the High Frequency amplifiers. Power application is controlled by S401, a six-pole, five position switch. The extreme positions of the switch are OFF. The other positions allow the choice of operating either Channel 1 or 2 alone or both together. S402 and S403 control the application of B-plus and filament power to the hydrophone circuits.

H. TSE Cabinet

Refer to Figures 12, 13 and 14. The cabinet circuits interconnect the receptacles for all the plug-in units and provide controls for the hydrophone circuits. The receptacles for the plug-in amplifiers are wired to the hydrophone receptacles and to the power supply plug-in unit. The controls for the amplifier circuits are contained in the units themselves. The hydro-

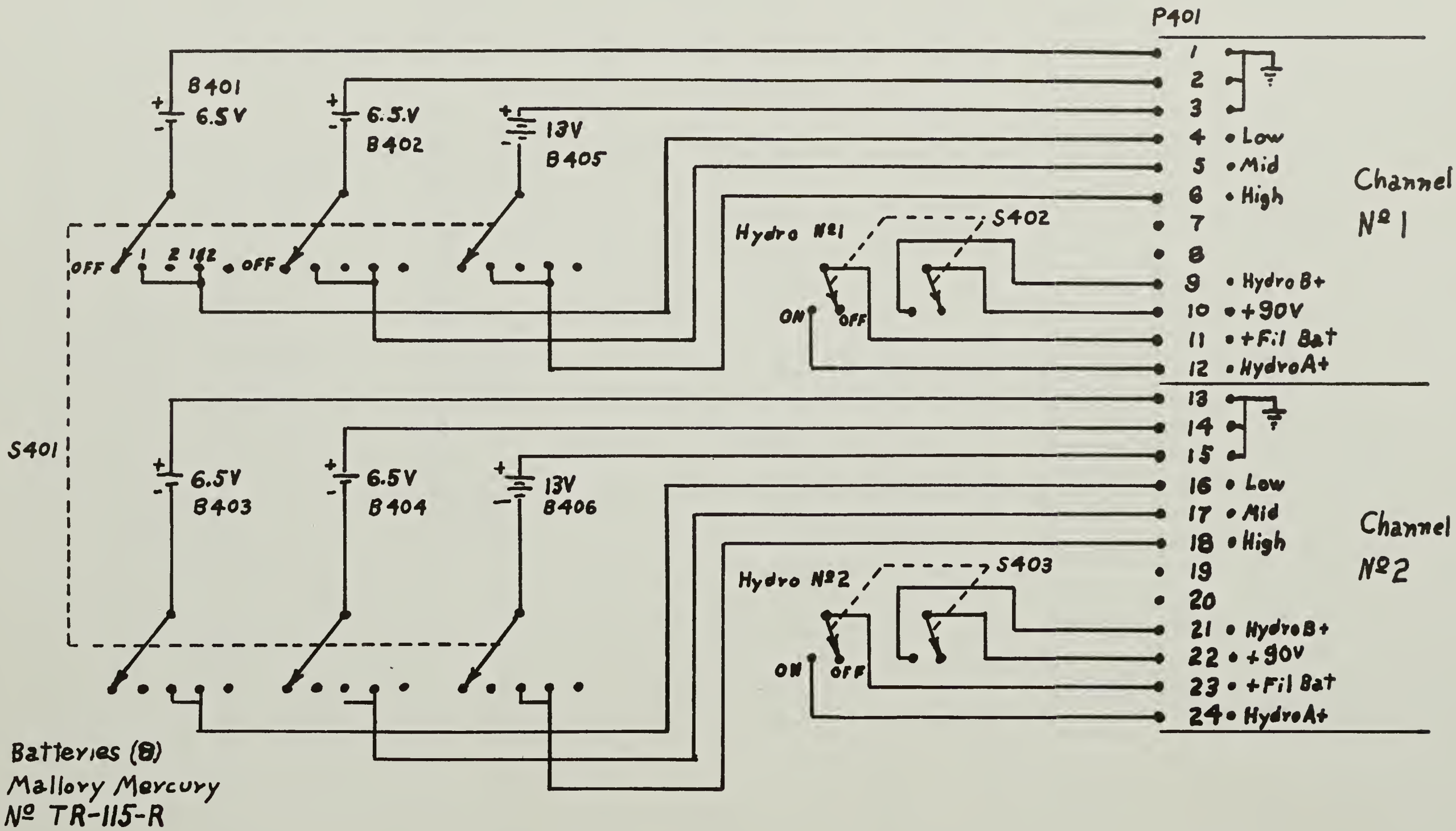


FIGURE 11 TSE AMPLIFIER POWER SUPPLY CIRCUIT

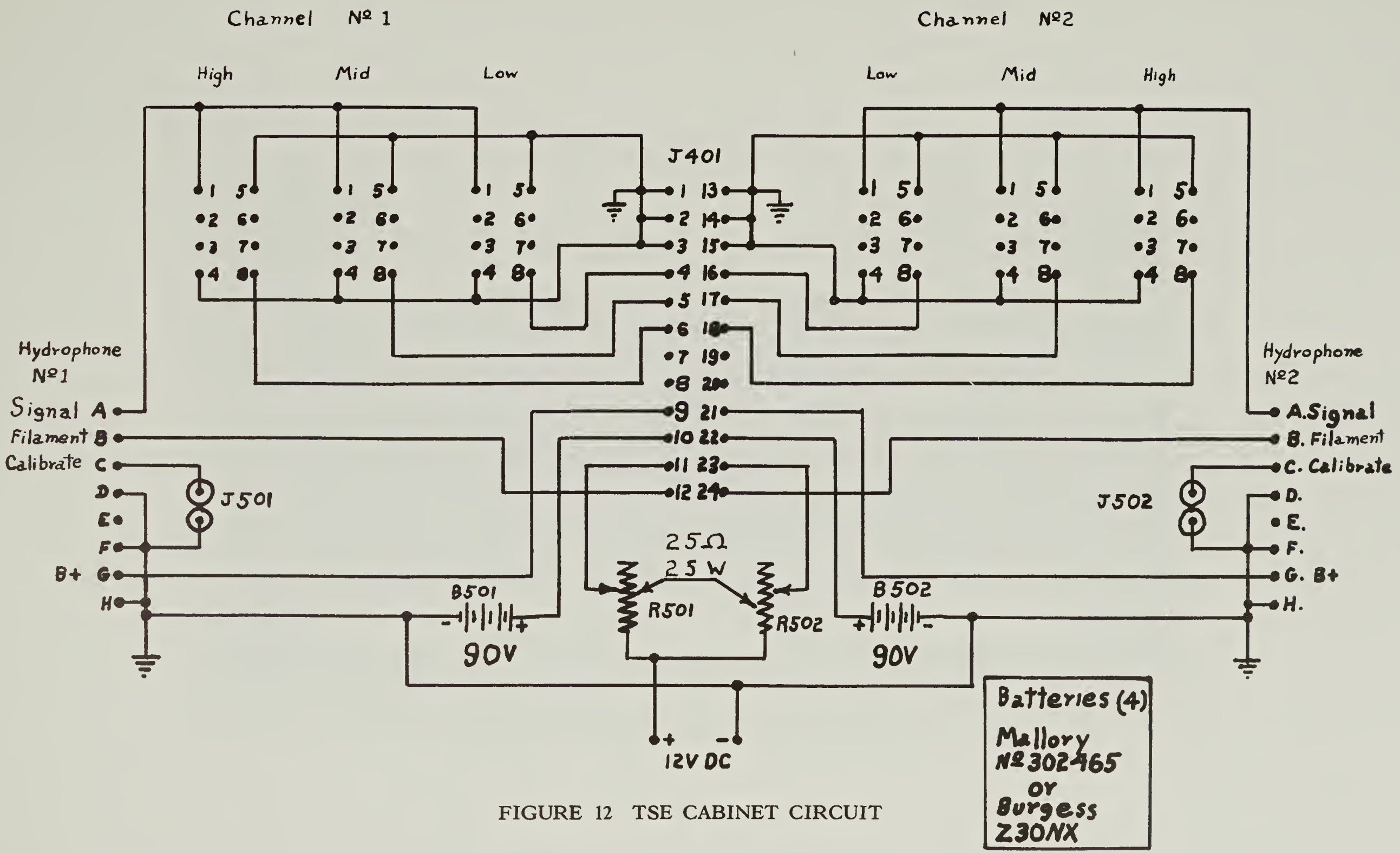


FIGURE 12 TSE CABINET CIRCUIT

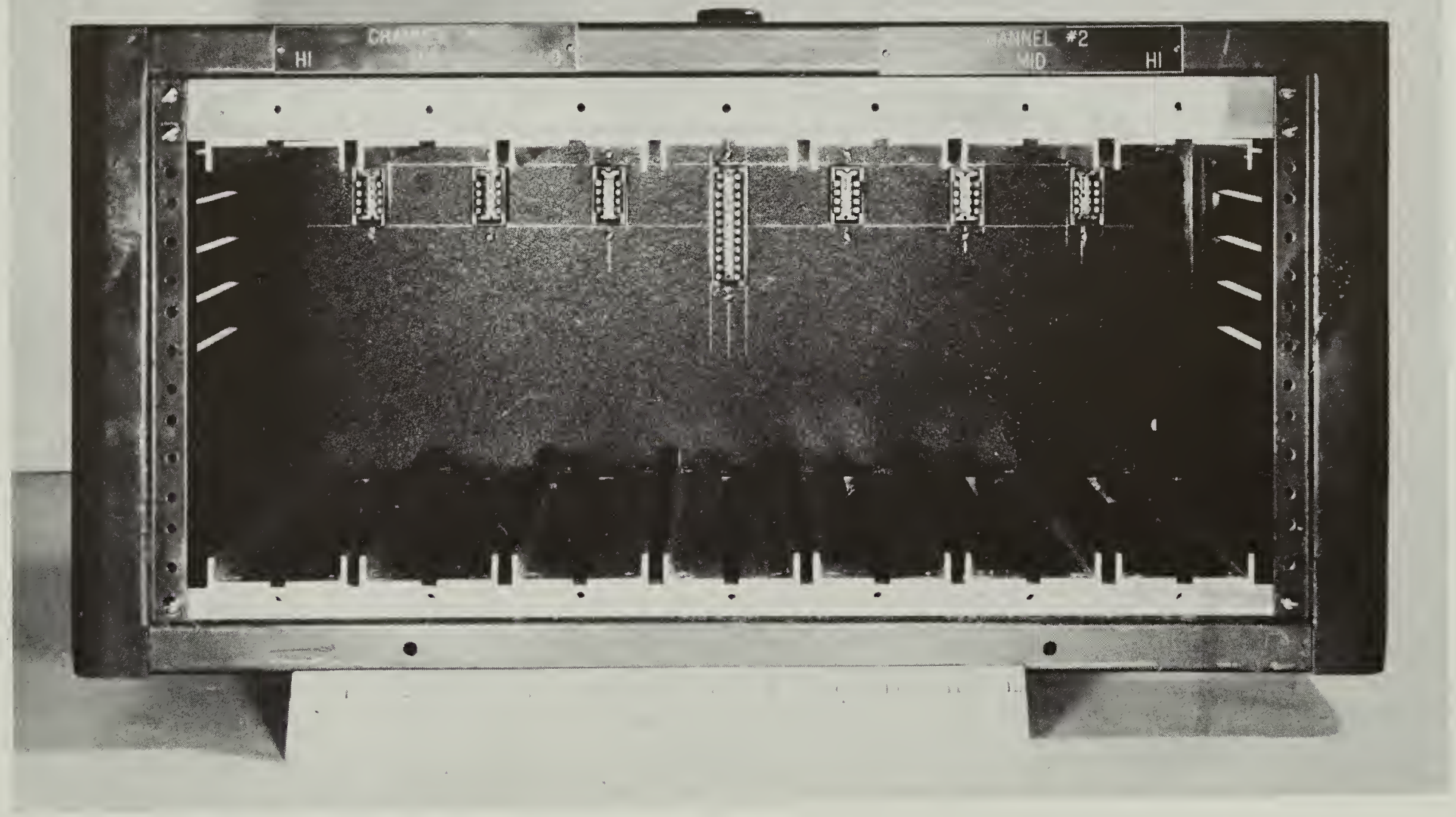


FIGURE 13 TSE CABINET, PLUG-IN UNITS REMOVED

phone circuit power is controlled by switches in the power supply plug-in unit except for filament power in the case of the WHOI hydrophone. Because of the appreciable voltage drop in the hydrophone cable line caused by the 300 ma. filament current, a 12 volt supply is required to obtain the required 6 volts at the tube filaments. R501 and R502 are connected in series with the filament lines and used to adjust the filament current to the proper value. The calibration signal connection to the hydrophones is available at the binding-post terminals J501 and J502, at the rear of the cabinet.

III INSTALLATION AND OPERATION

A. Physical Installation

The cabinet dimensions are 10-1/2 inches high, 21-1/2 wide and 15 deep. The equipment weighs 54 pounds.

The cabinet may be secured by bolting through the bottom plate.

The location and attitude of the cabinet should be made with consideration of the following factors:

1. The galvanometer connections at the front should be convenient for the operator to handle and be near to the recording camera. Note that it is desirable to be able to view the galvanometer traces while adjusting amplifier gain.

2. A fair lead-in must be provided at the rear of the cabinet for the hydrophone cable, oscillator, and storage battery connections. The rear of the cabinet should also be accessible for adjusting the filament current controls if the WHOI hydrophone is used.

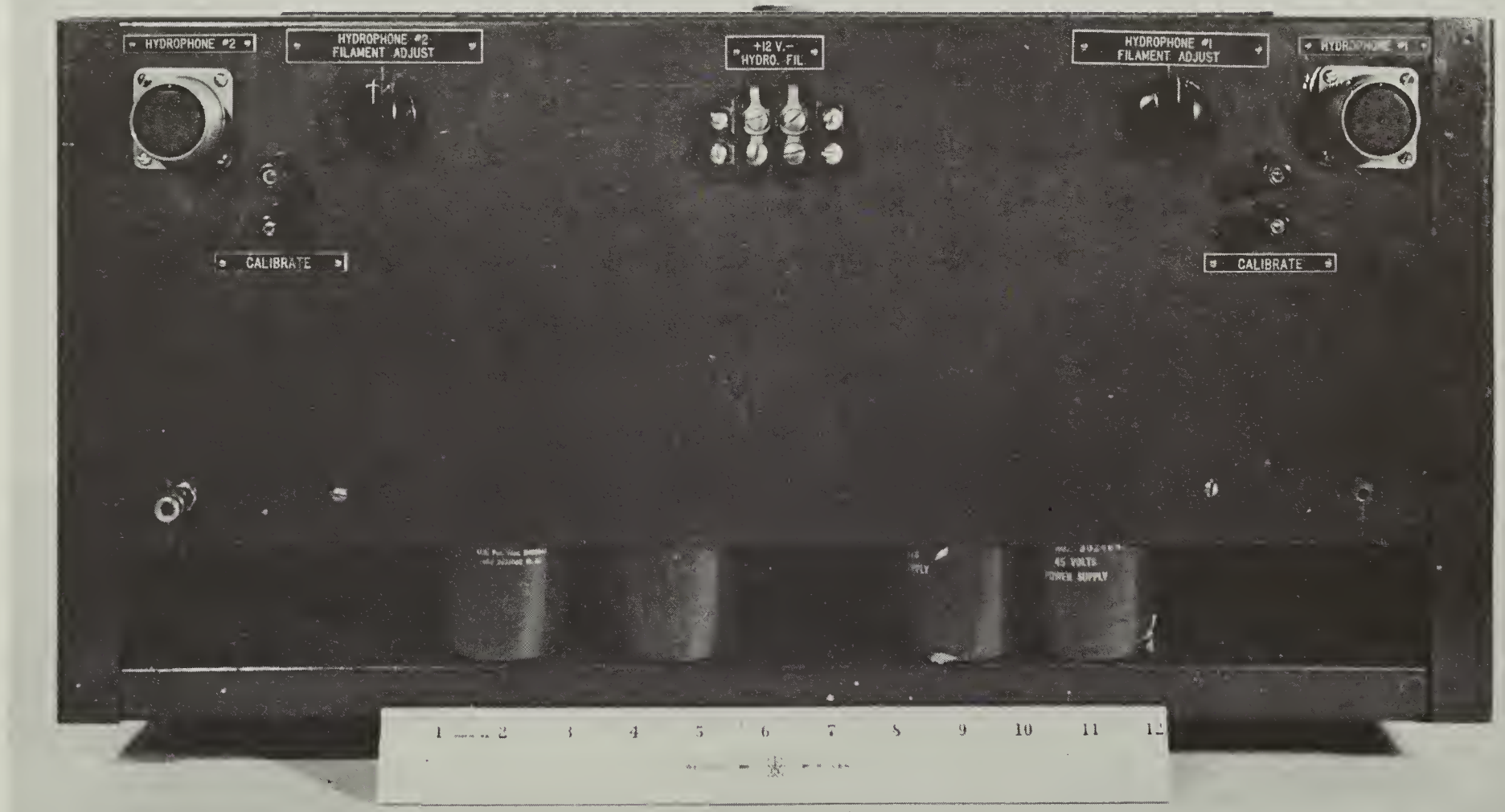


FIGURE 14 TSE CABINET, REAR VIEW

3. Overhead clearance of about 12 inches is required for opening the top door of the cabinet to check or replace the hydrophone 'B' batteries.

4. The cabinet should not be mounted adjacent to sources of great heat (steam radiators, for example).

B. Electrical Connections

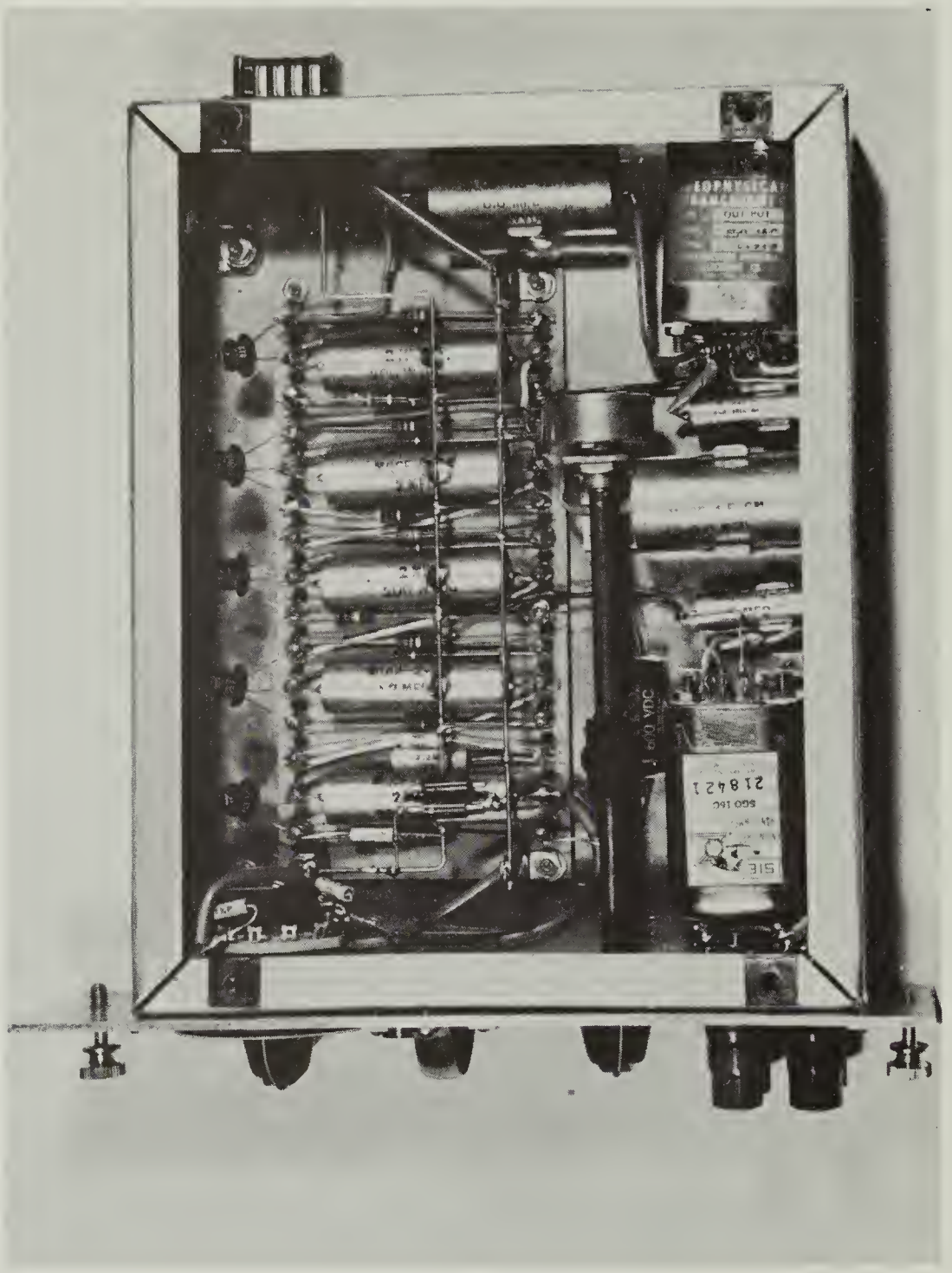
Electrical installation of the TSE consists of plugging in the hydrophone cables and galvanometers in the receptacles provided. The galvanometer terminals will accept National or General Radio banana-plugs as well as act as binding-post terminals. It is usually convenient to use the binding post connection for inserting the galvanometer damping resistors and the banana plugs for the galvanometer connection. If a galvanometer connection is not being used, it should be terminated by a low resistance (preferably 12 ohms).

If the WHOI hydrophone circuit is used, a 12 volt storage battery supply must be connected to the terminal board at the rear of the cabinet. The filament current controls may be conveniently adjusted when the connections are made by inserting an ammeter in series with one battery lead, turning on the hydrophone supplies one at a time, and adjusting the currents to 300 milliamperes.

C. Operating Procedures

Refer to Figures 1, and 15-18. All the TSE operating controls are on the front panel of the cabinet. The power controls are on the black power supply plug-in unit in the center of the panel. The gain controls are at top and bottom of each amplifier plug-in unit.

The 3 power switches are turned on just before the hydrophone cables are slacked off. Normally the extreme right-hand OFF position of the



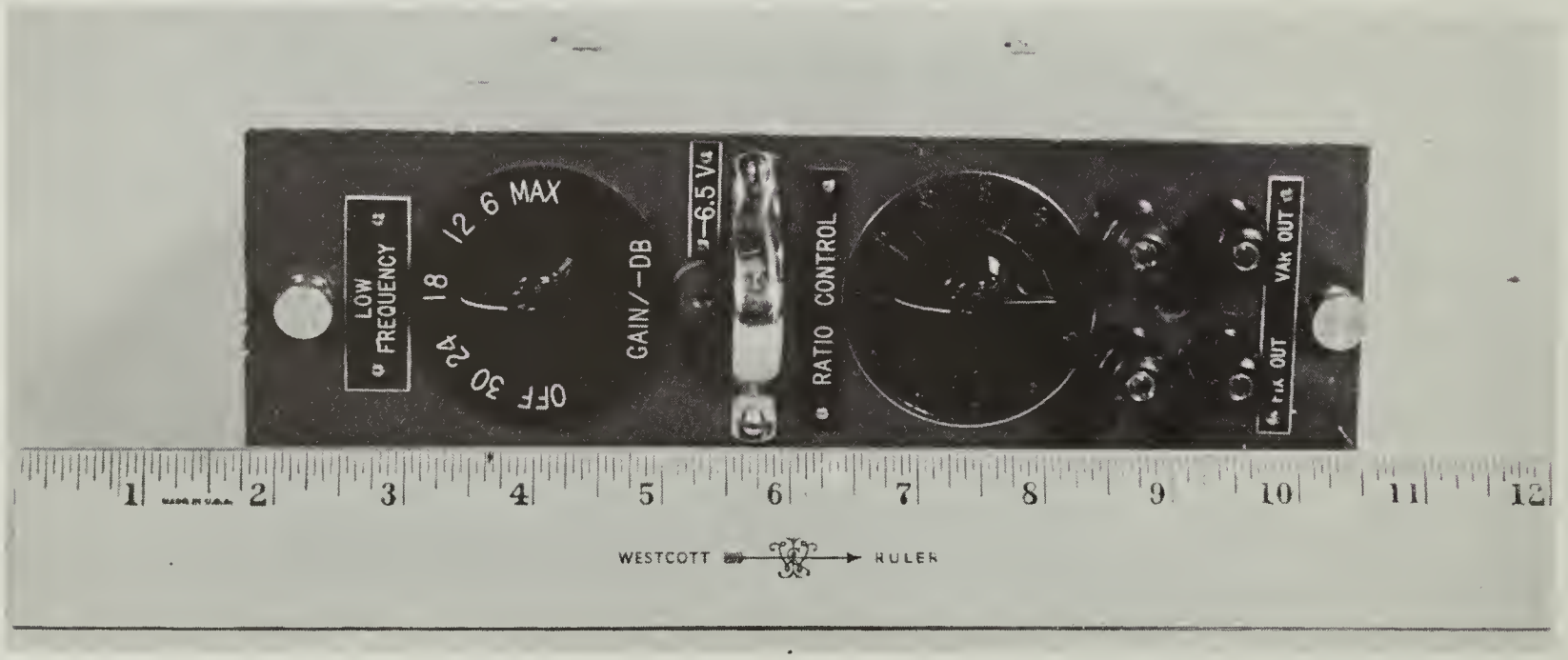


FIGURE 15 TSE LOW FREQUENCY AMPLIFIER

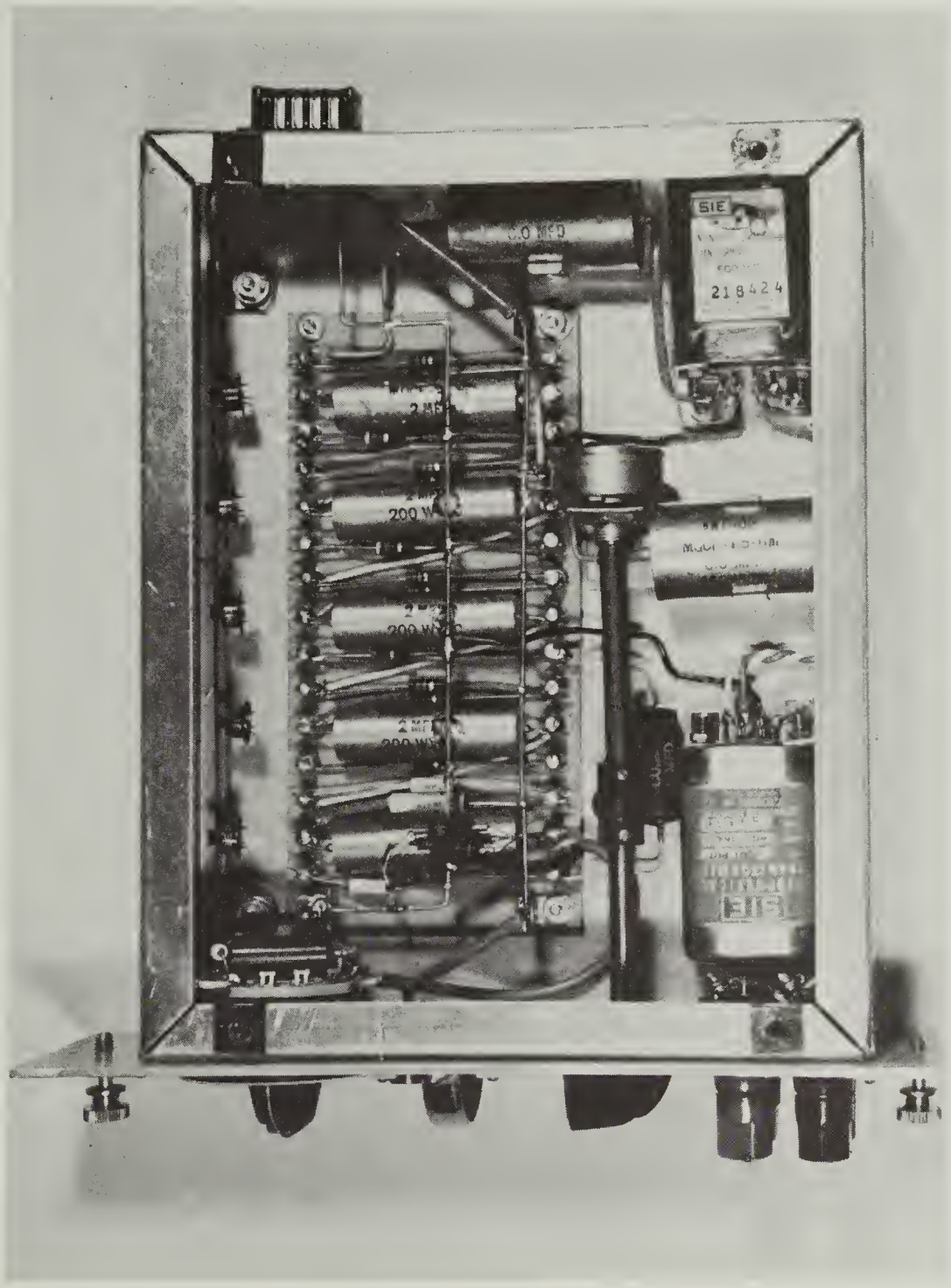


FIGURE 16 TSE MID FREQUENCY AMPLIFIER

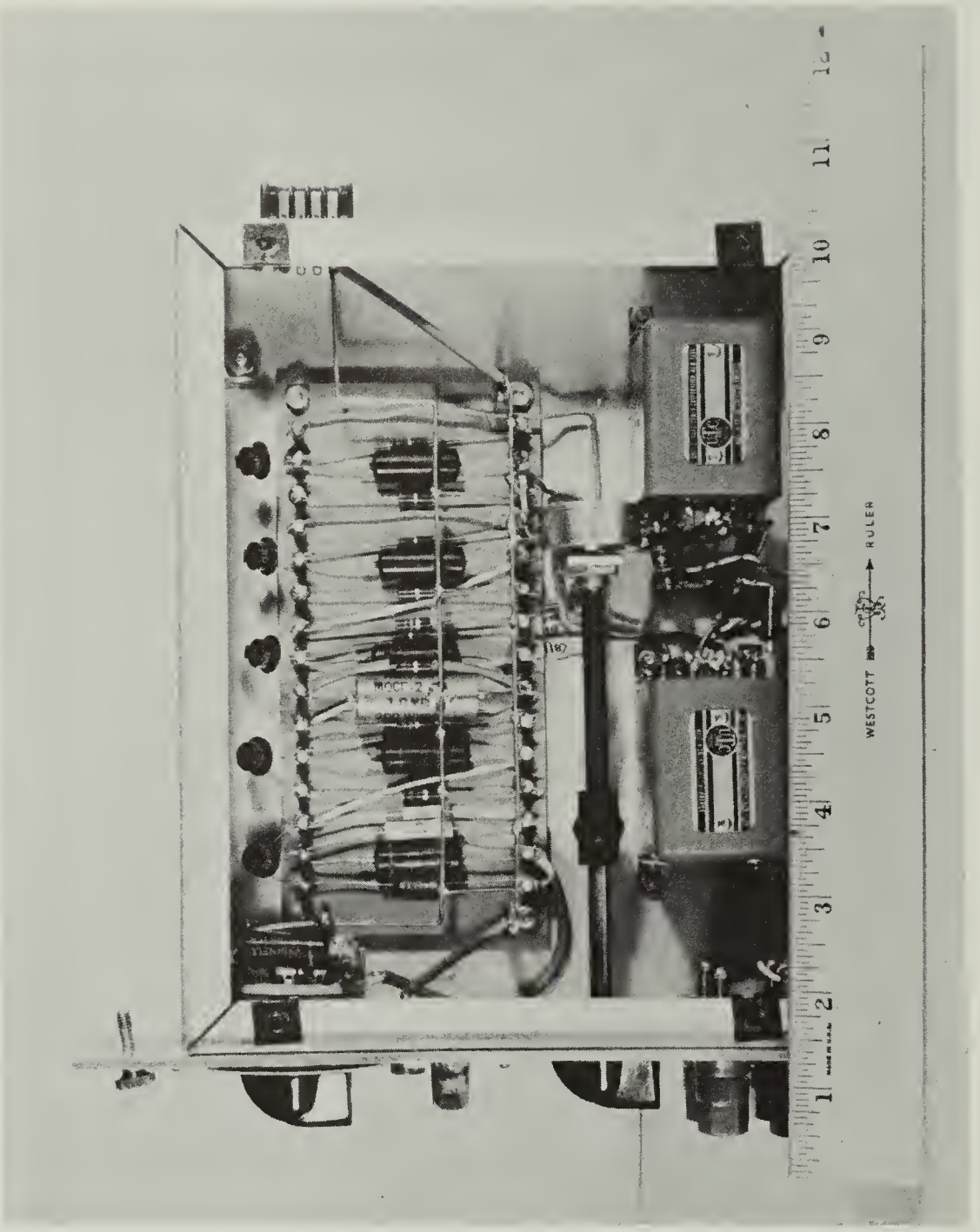


FIGURE 17 TSE HIGH FREQUENCY AMPLIFIER

amplifier power switch will be used in conjunction with the ON position labeled '1 & 2'. The hydrophone power switches are ordinary toggle types. The power switches are turned OFF after the recording camera is shut down.

The top gain control of each amplifier is the 'master' i.e., it controls the gain of both outputs. It is a step control arranged to provide approximately 6 db. attenuation per step.

The bottom gain control of each amplifier is the 'ratio control'. It is a continuously variable attenuator and controls the gain of the variable output only.

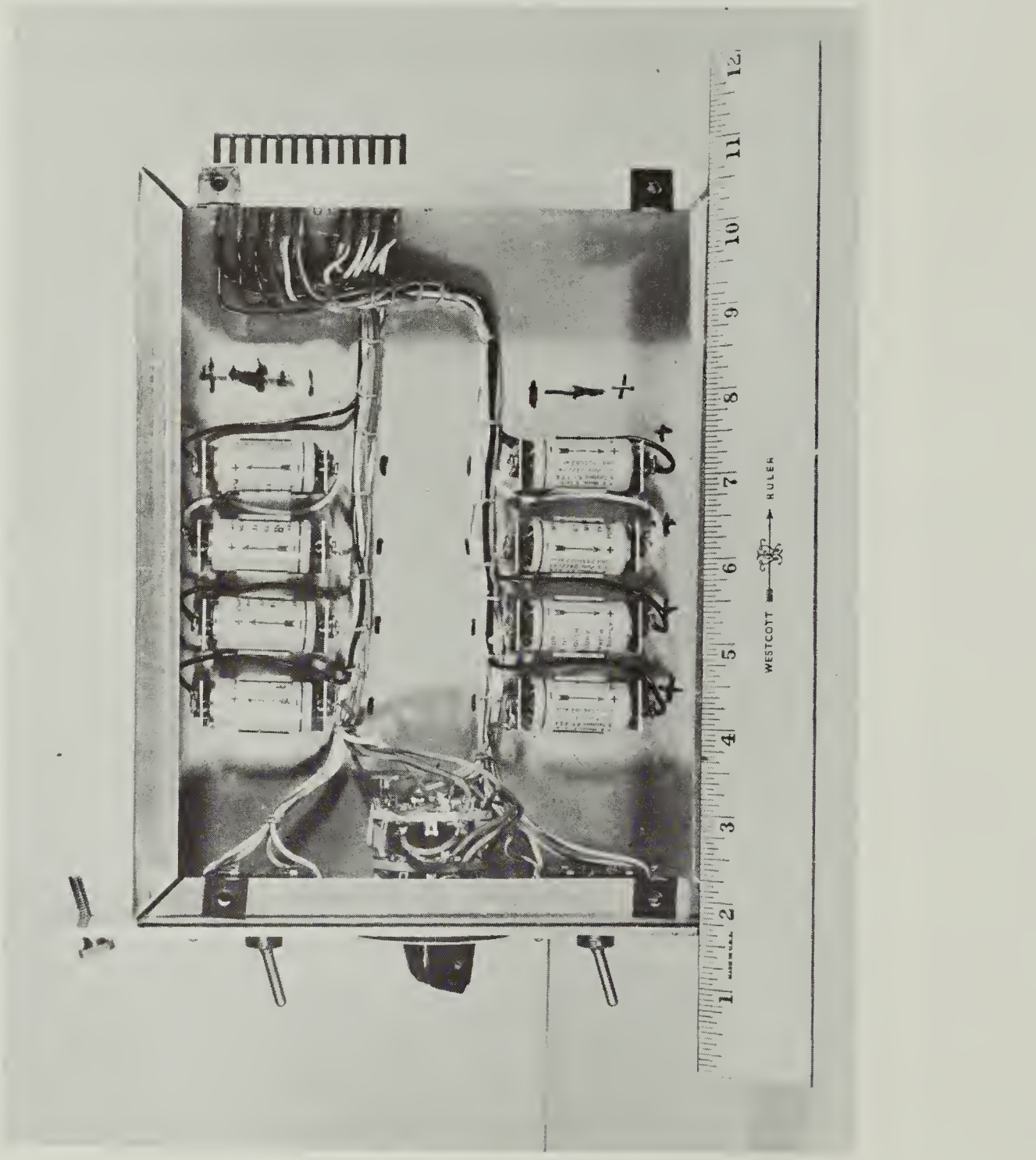
The test point under the master gain control may be used to check the battery supply of each amplifier.

IV MAINTENANCE AND TROUBLE SHOOTING

A. General

The only routine maintenance required for the TSE is the periodic replacement of batteries. Under usual operating conditions, this will have to be done about once per year.

Care should be exercised to avoid exposure of the equipment to environmental temperatures in excess of 60 degrees Centigrade. The germanium transistors are sensitive to temperature changes and will fail if exposed to high temperatures for any length of time. Special caution should be observed when using a soldering iron inside the amplifier chassis. The proper technique for soldering transistors into the circuit is explained in



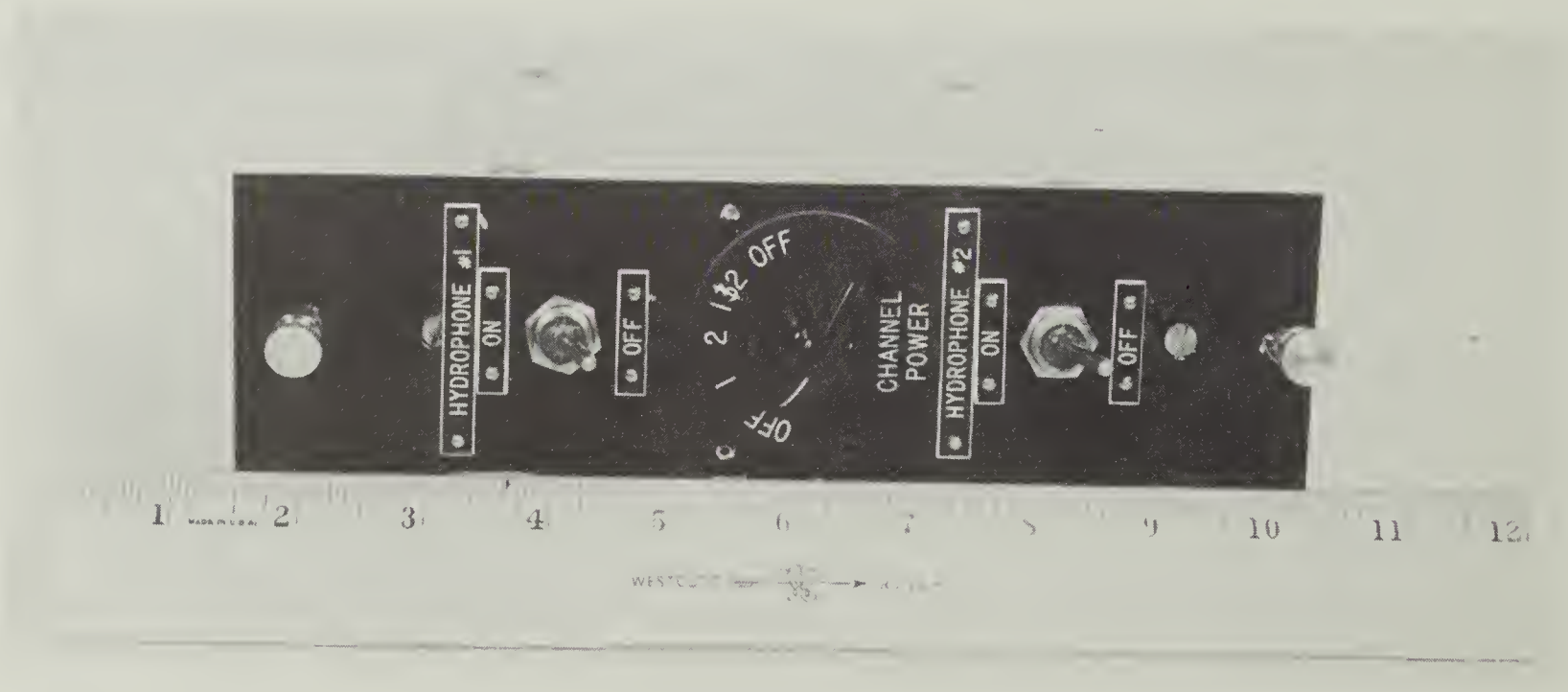


FIGURE 18 TSE AMPLIFIER POWER SUPPLY

Paragraph D below. The amplifier circuits are designed to show negligible change in performance over the temperature range O to 40 degrees Centigrade.

B. Batteries

The amplifier batteries may be checked at the test points provided on each amplifier. The hydrophone batteries may be checked by lifting the top cover of the cabinet and making measurements directly on the battery terminals. Battery life data is given in the following table:

SYMBOL	VOLTS		TYPE	FUNCTION	LIFE*
B401-B404	6.5		Mallory TR-115R	Low- and Mid-Freq. Amps.	200
B405 B406	13.0	(2)	Mallory TR-115R	High Frequency Amplifiers	100
B201	1.34	(2)	Mallory RM-42R	LGO Hydrophone Filament	500
B501 B502	90	(2)	Mallory 302465	LGO Hydrophone B-plus	200
B501 B502	90	(2)	Mallory 302465	WHOI Hydrophone B-plus	100
B501 B502	90	(2)	Burgess Z30NX	LGO Hydrophone B-plus	100
B501 B502		(2)	Burgess Z30NX	WHOI Hydrophone B-plus	50

* Minimum Rated Operating Hours at 25°C

C. Plug-in Units

The plug-in units may be removed by loosening two captive knurled screws and pulling them out of the cabinet.

A test cable is stored under the top cover of the cabinet for use in operating an amplifier unit outside of the cabinet.

The following features of the equipment should be noted for use in emergency:

1. The high frequency amplifier may be operated at 6.5 volts at reduced gain.

2. The low-and mid-frequency amplifiers are identical except for two capacitors, C9 and C10. With small effort, one type may be substituted for the other.

3. If desired, both recording channels may be used with one input by connecting a shielded wire from one hydrophone input plug to the other (Pin A).

Gain measurements of the low- and mid-frequency amplifiers should be made as follows:

1. Terminate the galvanometer connections with 12 ohm resistors.

2. Use an input voltage of 1 to 2 millivolts (Pin 1).

3. The gain measured should be about that shown in Figure 5.

4. A Ballantine VTVM or oscilloscope may be used for the above measurements.

Gain measurement of the high-frequency amplifiers should be made as follows:

1. Terminate the galvanometer connections with 2200 ohm resistors.

2. Use an input voltage of 1 mv. at 2000 cps.

3. Read 60 microamperes output on a Simpson Model 260 meter (100 microamp scale) or 40 microamps on a Triplett Model 630 (60 microamp scale). The meters are connected across the galvanometer terminals.

D. Transistor Checker

If a transistor failure is suspected, it may be checked on the LGO

Transistor Checker Model 102B shown in Figure 20. It is also good practice to check a new transistor before connecting it into a circuit.

Only one type of transistor is used in the TSE. It is a PNP-type manufactured by the General Electric Company and designated 2N43. The three connections to the transistor are in line. The center wire is the Base. At one end and relatively close to the Base is the Emitter wire. At the other end and relatively far from the Base is the Collector wire. The transistor is connected to the clip leads as shown in Figure 20.

Two quantities are measured on the transistor checker: (1) I_cO, the zero-bias current of the transistor; (2) I_a, the transistor current for a given bias. These are crude checks on transistor performance but are adequate for present purposes.

To check a 2N43 transistor:

1. Place the type-selector switch to PNP position.

2. Connect the transistor to the clip leads as shown in Figure 20.

3. With the scale dial at 0, depressing the test button should give a reading of no more than .02 milliamperes. If the reading is greater than this value, do not use the transistor in the TSE.

4. With the test button depressed, rotate the scale dial until the meter reads .5 ma. The dial reading should be between 30 and 35. If the dial reading is greater than 35, do not use the transistor in the TSE.

5. The battery test button should be depressed periodically to check the condition of the battery in the checker. The meter should read between .9 and 1.0 milliamperes if the battery is good.

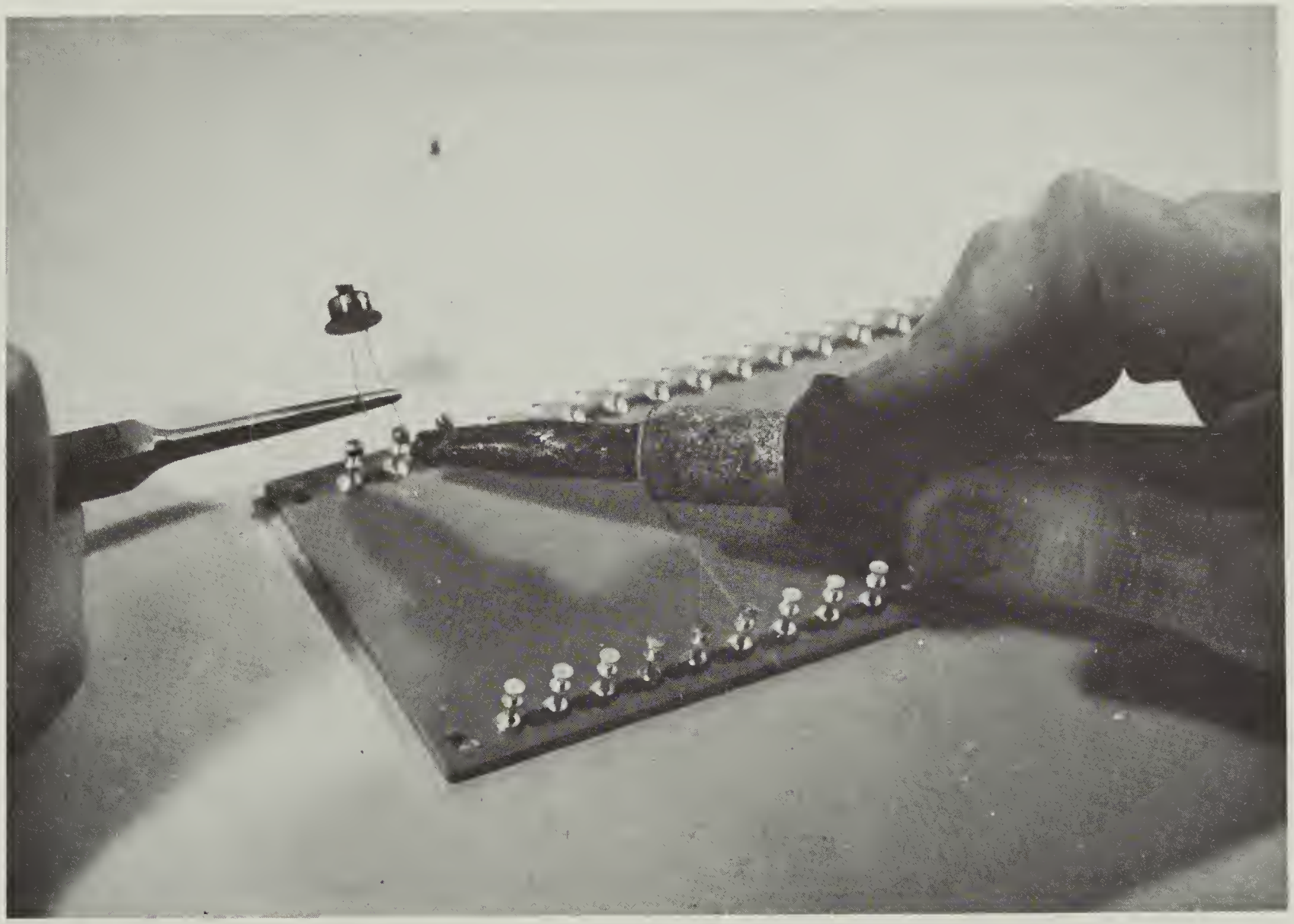


FIGURE 19 TRANSISTOR SOLDERING TECHNIQUE

If a transistor is to be removed from or wired into a circuit, great care should be used in soldering the transistor leads. See Figure 19.

A pair of pliers should always be used to hold the transistor lead at a point between the transistor body and the point of application of the heat.

When wiring a transistor into a circuit, first place a bead of solder on the terminal. Then, holding the transistor lead with pliers as explained above, place the lead next to the solder bead. Using a low wattage (20 to 50 watts) iron, touch the bead just long enough for the beaded solder to flow, and remove the iron. Hold the transistor wire firmly until the solder resolidifies, as shown by a change in color of the bead. After soldering all three terminals, check the solder joint by moving the transistor body and flexing the leads once or twice.

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FIGURE 20 TRANSISTOR CHECKER

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